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Heat acclimatization during summer running in the northeastern United States

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ABSTRACT

ARMSTRONG, L. E., R. W. HUBBARD, J. P. DELUCA, and E. L. CHRISTENSEN. Heat acclimatization during summer running in the northeastern United States. *Med. Sci. Sports Exerc.*, Vol. 19, No. 2, pp. 131–136, 1987. Five highly trained distance runners (DR) were observed during controlled 90-min thermoregulation trials in spring (T_1) and late summer (T_2) to document the nature of heat acclimatization in the northeastern United States. These trials simulated environmental (30.3 ± 0.1°C dry bulb, 34.9 ± 0.5% relative humidity, 4.47 $m \cdot s^{-1}$ wind speed) and exercise (treadmill running at 80, 120, 160, and 200 $m \cdot min^{-1}$) stresses encountered by DR during summer training in the northeastern United States. Between T_1 and T_2, DR trained outdoors for 14.5 ± 0.4 wk, but consequently exhibited few physiological adaptations classically associated with heat acclimatization. Statistical comparison of T_1 and T_2 indicated no significant differences in mean heart rate, rectal temperature, sweat Na^+ and K^+, plasma Na^+ and K^+, or change in plasma volume during exercise. Mean weighted skin temperature was unchanged except at 50 min of exercise, and sweat rate was also unchanged except during the initial 30 min segment: 73 ± 6 vs 93 ± 8 $ml \cdot m^{-2} \cdot h^{-1}$. Significant decreases ($P < 0.05$) in submaximal $\dot{V}O_2$ were observed: T_1 vs T_2 values were 13.97 ± 0.27 vs 10.19 ± 1.19, 31.38 ± 1.15 vs 27.91 ± 1.45, and 44.97 ± 0.85 vs 41.24 ± 0.97 $ml \cdot kg^{-1} \cdot min^{-1}$, at treadmill speeds of 80, 120, and 200 $m \cdot min^{-1}$, respectively. We conclude that DR did not require 14.5 wk of summer training to maintain safe rectal temperatures (≤38.4°C) during T_1, which simulated the hottest days of summer in the northeastern United States. Keywords:

HEAT ACCLIMATIZATION, RUNNING, RECTAL TEMPERATURE, OXYGEN UPTAKE, SWEAT, PLASMA VOLUME, SODIUM, POTASSIUM, Sweat cooling, reprints, athletes, adaptation, training

The partial heat acclimatization which distance runners exhibit during winter heat tolerance tests has been attributed to stimulation of sweating and cutaneous blood flow during strenuous workouts (15), high maximal oxygen consumption ($\dot{V}O_{2max}$), increased evaporative cooling (9), greater cardiovascular stability (19, 22), more favorable body fluid dynamics (17), earlier onset of sweating (4, 13), and greater sweat sensitivity (22). For example, two previous investigations (9, 15) independently observed the effects of high-intensity cool weather interval training (70 to 90% $\dot{V}O_{2max}$) and reported that collegiate distance runners responded to winter heat tolerance tests as though they were heat acclimatized, even though they had not been exposed to heat since the preceding summer. In contrast, Strydom and Williams (19) criticized the above interpretation of data because their 4-h heat tolerance test indicated that a strenuous physical conditioning program conducted at cool environmental temperatures reduced rectal temperature (T_{re}) and heart rate (HR) during the first 2 h, but thereafter indicated that T_{re} and HR rose to pre-acclimation levels. They concluded that exercise in the heat was required for full heat heat acclimation.

However, the duration of daily training and heat exposure varies between athletes. Also, the maximal heat tolerance required in moderate climates (e.g., the northeastern United States) is quite different from that required for hot climates (e.g., the southwestern United States). Therefore, a regional definition of heat acclimatization—which utilizes the most severe environmental conditions experienced in a given geographical area—is warranted. In the present investigation, heat acclimatization is specifically defined as an improvement in the ability to tolerate the hottest environmental conditions experienced in the northeastern United States.

The purpose of the present investigation was to examine heat acclimatization in the northeastern United States by comparing the spring and summer heat tolerance of highly trained distance runners in chamber conditions which simulated the outdoor thermal stress recorded in the northeastern United States during this study (30.3°C). Classical heat acclimatization, and metabolic and fluid indices were measured during controlled thermoregulation trials designed to simulate environmental and exercise stresses which marathoners and ultra-marathoners encounter during summer training. Between spring and summer trials, subjects trained and competed in road races for 14.5 ± 0.4 wk. This investigation is unique because responses were observed in athletes using their own coaches and training/racing schedules, and because it measured long-term physiological adaptations resulting from more than 3 months of summer running.

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METHODS

The subjects of this investigation were four male and one female highly trained distance runners. The female was a nationally ranked ultra-marathoner; two of the males also competed in ultra-marathons during the course of this investigation. The mean best marathon time for these distance runners was 2:38:00 ± 0:06:00 ($N = 4$). The age, height, and body mass of these athletes (mean ± SE) were: 32 ± 3 yr, 175 ± 4 cm, and 67.688 ± 2.577 kg. Subjects followed their normal training schedules throughout the entire investigation, keeping daily training logs for 3 months prior to each thermoregulation trial.

Subjects were briefed, and written informed consent was obtained prior to participation in this investigation. Thermoregulation trials were conducted in the spring (T_1) and summer (T_2). The mean number of weeks between trials was 14.5 ± 0.3. Ambient temperature data for March through August (National Climatic Data Center, Asheville, NC) is presented in Figure 1. Between T_1 and T_2, the maximum daily temperature of only 3 d (3% of the total days) exceeded the 30.3°C chamber conditions (Fig. 2). The outdoor dew point temperature for the months of March through August averaged −8.6, −1.1, 6.6, 11.0, 15.2, and 13.8°C, respectively; the chamber dew point temperature averaged 13.2 ± 0.5°C, and thus simulated the ambient vapor pressure which distance runners experienced during ultra-distance training runs.

Subjects were instructed to drink large quantities of water on the day before the trial to ensure adequate hydration. A pre-trial urine sample was analyzed for specific gravity. If any subject had urine specific gravity over 1.030, that subject consumed more water until specific gravity was below 1.030. Immediately before testing, subjects showered without soap, inserted a rectal probe 8 cm beyond the anal sphincter, and dressed in electrolyte-free running gear. Heights were recorded, skin thermistors were placed on the forearm, calf, and chest, and ECG electrodes were applied.

Trials (Fig. 2) were conducted in an environmental chamber at 30.3 ± 0.1°C, 34.9 ± 0.5% relative humidity with a 4.47 $m \cdot s^{-1}$ wind speed. Subjects stood in the chamber for 20 min to allow body fluids to equilibrate to upright posture, after which an antecubital blood sample and a body weight were taken. Subjects completed 10 min of continuous treadmill exercise at each of three belt speeds: 80, 120, and 160 $m \cdot min^{-1}$. The final 60 min were run at 200 $m \cdot min^{-1}$. Subjects stepped off the treadmill briefly for a body weight (Mettler Balance, Hightstown, NJ; accuracy ± 10 g) after 30, 50, and 70 min of exercise.

A semi-automated data collection system was used to monitor T_{re} and skin temperatures and to analyze expired gases. A gasmeter (Parkinson-Cowan, OEM Medical, Richmond, VA), oxygen analyzer (Applied Electrochemistry, Sunnyvale, CA, model S3A), and carbon dioxide analyzer (Beckman Instruments, Fullerton, CA, model LB2) were part of this system. Gas analyzers were calibrated before each trial, using calibration gases with known concentrations. Temperatures from rectal and skin thermistors on arm, chest, and calf (Yellow Springs, Inc., Yellow Springs, OH) were monitored at 2-min intervals throughout the trial. Mean weighted skin temperature (MWST) was calculated by using this formula: MWST = (0.14 arm) + (0.5 chest) + (0.36 calf). HR was monitored continuously with an EKG telemetry system (Hewlett-Packard, Inc., Palo Alto, CA). A blood sample and body weight were taken immediately at the end of exercise. Subjects stood for 20 min, after which the final blood sample and

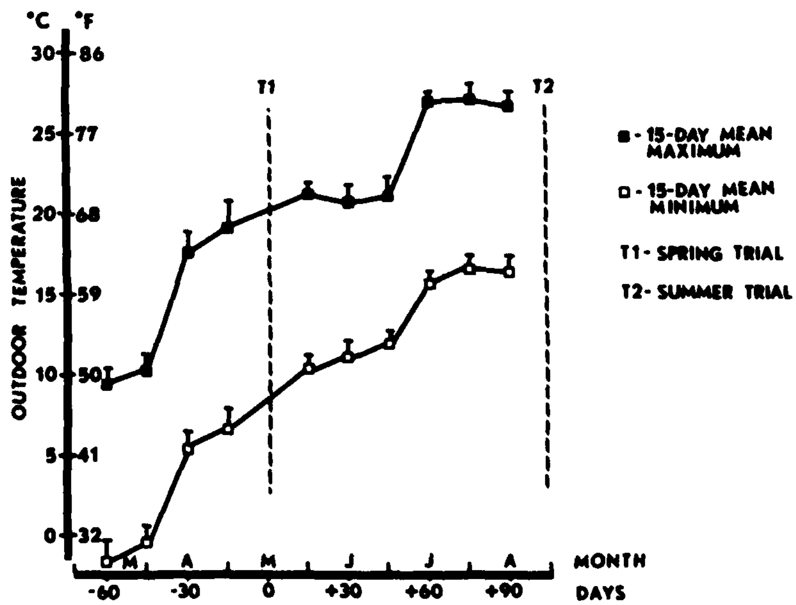

Figure 1—Mean (±SE) outdoor maximum and minimum temperatures at the location of this investigation.

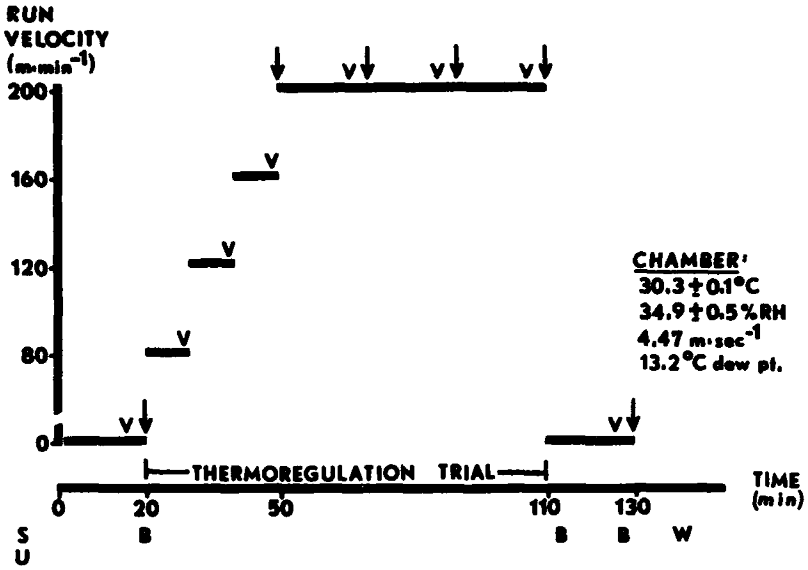

Figure 2—Design of thermoregulation trials T_1 and T_2 in the environmental chamber. Arrows denote body weight measurements (±10 g). V = oxygen uptake; S = pre-trial shower; U = urine sample; B = venous blood sample; W = whole body washdown.

body weight were taken. Blood samples were analyzed for micro-hematocrit and hemoglobin (Hycel Inc., Houston, TX). These values were used to calculate percentage plasma volume changes (6). Plasma sodium (Na^+) and potassium (K^+) were also analyzed using a flame photometer (Rainin Instruments Inc., Woburn, MA, model FLM3).

Body weight differences were used to calculate sweat rate (SR), after correction for water intake and urine output. Sweat electrolyte losses were measured after the post-exercise blood sample, using the whole body washdown technique of Vellar (21). During work bouts, all dripping sweat (which was minimal because of the dry conditions and air flow in the climatic chamber) was blotted from the hair and skin with electrolyte-free towels. The subjects, clothing, and towels were washed using a known volume of deionized water (7.66 l), and aliquots were analyzed for Na^+ and K^+ on a flame photometer.

A two-way ANOVA and the Student-Neuman-Keuls *post-hoc* analysis were used to compare T_{re} and MWST within and between trials T_1 and T_2. Paired *t*-tests were used to compare differences between the means of trials T_1 and T_2. All data were expressed as mean ± SE.

RESULTS

Table 1 presents a comparison of subject pre-trial status for the T_1 and T_2 trials. No significant differences were found in training habits (except for number of interval workouts per month) or body water indices.

Daily training records, maintained during the 14.5 wk interval between T_1 and T_2 indicated that subjects ran most workouts during the noon hour (76.1%), and fewer workouts during the later afternoon (6.8%) and morning (17.1%). This suggests that the majority of training sessions (82.9%) offered distance runners a thorough heat acclimatization stimulus because they were run during noon or later afternoon time periods.

Subjects rated daily outdoor workouts on a 5-point scale. These ratings were distributed as follows: very easy = 2.7%; easy = 30.1%; somewhat hard = 34.9%; hard = 18.3%; and very hard = 14.0%. The pace of outdoor running was not reported by distance runners. However, a previous study (14), which related ratings of perceived exertion to relative work intensities, suggests that these ratings relate to the following approximate work intensities: very easy = 25% $\dot{V}O_{2max}$; easy = 45% $\dot{V}O_{2max}$; somewhat hard = 60% $\dot{V}O_{2max}$; hard = 75% $\dot{V}O_{2max}$; and very hard = 85% $\dot{V}O_{2max}$. This indicates that distance runners ran the majority (65%) of all training runs at approximately 45 to 60% $\dot{V}O_{2max}$, and that distance runners ran 83.3% of all workouts at approximately 45 to 75% $\dot{V}O_{2max}$. In the laboratory, direct measurements of $\dot{V}O_{2max}$ were not performed on distance runners, but we estimated the mean $\dot{V}O_{2max}$ of distance runners to be 69 ± 5 $ml \cdot kg^{-1} \cdot min^{-1}$ (2). Running at 200 $m \cdot min^{-1}$ during T_1 and T_2 required distance runners to utilize 44.97 and 41.24 $ml \cdot kg^{-1} \cdot min^{-1}$ oxygen (Table 2). Thus, T_1 and T_2 were conducted at approximately 60 to 65% $\dot{V}O_{2max}$ and were representative of training exercise intensities estimated via distance runner workout ratings (above).

The T_{re} (maximum = 38.3° to 38.4°C) and MWST for T_1 and T_2 appear in Figure 3. The only significant difference appeared at 50 min of exercise, when MWST was significantly higher during T_2.

A significant ($P < 0.05$) between-season difference in $\dot{V}O_2$ was observed during exercise at 80, 120, and 200 $m \cdot min^{-1}$ (Table 2). HR (Table 2) exhibited no T_1 vs T_2 differences at all measured trial segments.

SR (1.1 to 1.4 $l \cdot h^{-1}$) and sweat electrolyte losses for each trial are shown in Table 3. SR was higher only during the initial 30 min of exercise (run speed = 80 to

TABLE 1. Mean (± SE) training and body water parameters prior to T_1 and T_2.

Measurement	Unit	T_1	T_2	Statistical Significance
Training				
Training	$km \cdot d^{-1}$	13.7 ± 1.1	13.3 ± 1.1	NS*
Training	$d \cdot month^{-1}$	26 ± 1	25 ± 2	NS
Interval workouts	$d \cdot month^{-1}$	2.0 ± 0.6	0.7 ± 0.2	$P < 0.05$
Competition	$races \cdot month^{-1}$	1.2 ± 0.3	1.3 ± 0.3	NS
Body water indices				
Body weight	kg	67.688 ± 2.577	67.803 ± 3.143	NS
Urine specific gravity		1.023 ± 0.004	1.018 ± 0.002	NS
Hematocrit	%	43.5 ± 0.9	42.8 ± 0.4	NS

* NS = not statistically significant.

TABLE 2. Mean (± SE) oxygen uptake and HR during T_1 and T_2 at run velocities of 80, 120, 160, and 200 $m \cdot min^{-1}$.*

Measurement	Unit	Run Velocity ($m \cdot min^{-1}$)	T_1	T_2	Statistical Significance
Oxygen uptake	$ml \cdot kg^{-1} \cdot min^{-1}$	80	13.97 ± 0.27	10.19 ± 1.19	$P < 0.05$
		120	31.38 ± 1.15	27.91 ± 1.45	$P < 0.05$
		160	35.89 ± 1.93	35.00 ± 1.29	NS†
		200	44.97 ± 0.85	41.24 ± 0.97	$P < 0.05$
HR	$beats \cdot min^{-1}$	80	74 ± 4	84 ± 11	NS
		120	102 ± 6	113 ± 5	NS
		160	117 ± 6	120 ± 8	NS
		200	135 ± 7	143 ± 8	NS

* All measurements were taken after a minimum of 10 min steady-state exercise. Each mean represents five data points, except 200 $m \cdot min^{-1}$ values which represent 15 data points.
† NS = not statistically significant.

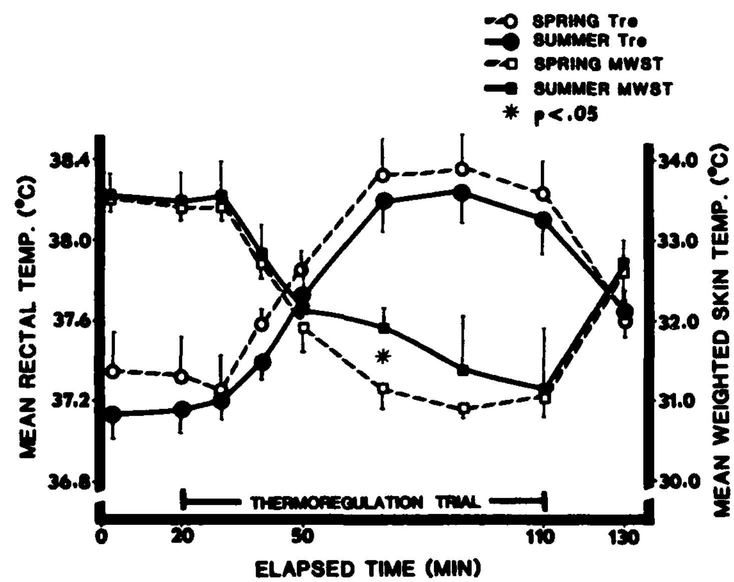

Figure 3—Tre and MWST during T1 and T2 trials (mean ± SE).

TABLE 3. Mean (± SE) whole body SR and sweat electrolyte values during T_1 and T_2.

Measurement	Unit	Run Velocity ($m \cdot min^{-1}$)	Time (min)	T_1	T_2	Statistical Significance
SR	$ml \cdot m^{-2} \cdot h^{-1}$	80–160	30	73 ± 6	93 ± 8	$P < 0.05$
		200	20	636 ± 42	683 ± 71	NS†
		200	20	754 ± 87	669 ± 109	NS
		200	20	592 ± 35	662 ± 63	NS
		Post	20	231 ± 23	262 ± 32	NS
Sweat Na^+ concentration	$mEq \cdot l^{-1}$	*	*	21 ± 6	31 ± 4	NS
Sweat K^+ concentration	$mEq \cdot l^{-1}$	*	*	4.1 ± 0.2	4.1 ± 0.2	NS
Sweat Na^+ loss	Total mEq	*	*	34 ± 9	51 ± 6	NS
Sweat K^+ loss	Total mEq	*	*	6.4 ± 0.3	6.7 ± 0.4	NS

* Represents the entire trial.
† NS = not statistically significant.

TABLE 4. Mean (± SE) plasma volume change, plasma Na^+, and plasma K^+ during T_1 and T_2.

Measurement	Unit	Time Interval	T_1	T_2	Statistical Significance
Plasma volume change	Δ%	Pre-post	−4.7 ± 2.0	−2.1 ± 1.9	NS*
		Pre-20 min post	−0.6 ± 2.1	−0.1 ± 1.6	NS
Plasma Na^+	$mEq \cdot l^{-1}$	Pre	140 ± 0.2	140 ± 0.7	NS
		Post	142 ± 0.4	142 ± 0.7	NS
		20-min post	140 ± 0.4	141 ± 0.9	NS
Plasma K^+	$mEq \cdot l^{-1}$	Pre	4.5 ± 0.1	4.3 ± 0.1	NS
		Post	4.7 ± 0.1	4.3 ± 0.1	NS
		20-min post	4.5 ± 0.1	4.5 ± 0.1	NS

* NS = not statistically significant.

160 $m \cdot min^{-1}$) during the summer; similar findings have been previously reported (4, 13). There were no T_1 vs T_2 differences in either sweat concentration or total milliequivalents lost. Plasma electrolytes and plasma volume changes (Table 4) also indicated that there were no T_1 vs T_2 differences.

DISCUSSION

The results of this investigation indicate that the physiological responses of highly trained distance runners did not change after 14.5 wk of summer heat exposure, when tested in conditions which simulated the hottest days of summer (30.3°C) in the northeastern United States. Although more severe ambient conditions during T_1 and T_2 might have demonstrated between-trial thermoregulatory differences (T_1 vs T_2), such a finding is extraneous to the purpose of this investigation. Heat acclimatization has been defined in many ways since the initial heat acclimation investigations of the 1930's (11); but in the present investigation, heat acclimatization referred to regional environmental conditions. Our findings do not indicate that distance runners should omit heat exposure from their training when preparing for hotter environments (>30.3%C) because these data are specific to: (a) northern areas of the United States (Fig. 1); (b) running speeds typical of ultra-marathon and marathon training (Fig. 2); and (c) thermoregulation at or near 30.3°C (Fig. 3). Had the distance runners of the present investigation trained in the southern United States, it is likely that they would have developed physiological adaptations indicative of greater heat tolerance, in spite of their high level of fitness and great cardiovascular stability at T_1 (19, 20, 23). Drinkwater (7) noted that optimal acclimatization procedures involve training in an environment which is comparable to the one in which competition will occur. Indeed, a similar approach was utilized to successfully acclimatize a marathon runner prior to the 1984 Summer Olympic Games (3).

The MWST (Fig. 3) during spring and summer trials decreased noticeably during exercise, probably due to the 592 to 754 $ml \cdot m^2 \cdot h^{-1}$ SR during exercise (Table 3) and the chamber conditions (13.2°C dew point, 4.47 $m \cdot s^{-1}$ wind velocity), which promoted evaporative cooling. The mean T_{re} (both T_1 and T_2) peaked at 38.3° to 38.4°C and decreased during the final 20 min of exercise, indicating that distance runners were neither storing heat nor experiencing dangerously elevated T_{re}. The only T_1 vs T_2 statistical difference ($P < 0.05$) was observed at 50 min of exercise, when the summer MWST was higher than the spring. Because T_{re} (Fig. 3) and SR (Table 3) were not significantly different at that point, we hypothesize that this T_1 vs T_2 difference was due to a greater cutaneous circulation during T_2. HR data supports this hypothesis, in that increased peripheral circulation reduces central blood volume and acts to increase HR in an effort to maintain cardiac output. The submaximal $\dot{V}O_2$ decreased significantly from T_1 to T_2 (Table 2), requiring that 8% less metabolic heat be dissipated (running at 200 $m \cdot min^{-1}$ for 60 min) during T_2 than during T_1. This decreased $\dot{V}O_2$ also supports our hypothesis of increased peripheral circulation because diversion of blood flow to the cutaneous vascular beds decreases $\dot{V}O_2$; the skin has lower oxygen requirements that muscle or internal organs. Other findings of reduced $\dot{V}O_2$ following heat acclimation have been explained in terms of improved metabolic efficiency (18) and altered muscle motor unit recruitment (16).

The T_1 vs T_2 responses of the female ultra-marathon runner in this investigation (not shown separately) were qualitatively and quantitatively similar to those of her male counterparts, with respect to HR, T_{re}, MWST, SR, sweat electrolytes, change in plasma volume during exercise, and submaximal $\dot{V}O_2$. In this respect, her physiological responses were different from the responses of the sedentary females, described by Fortney and Senay (8). Sedentary females in their study exhibited greater cardiovascular strain, lower evaporative cooling, greater peripheral distribution of blood, higher MWST, and a greater decline of plasma volume than males. Because physical training lowers the threshold for sweating, increases plasma volume, decreases HR, decreases MWST, and decreases T_{re} (4, 5, 10), the female distance runner in the present investigation (a nationally ranked ultra-marathoner) provides evidence that previously reported male-female thermoregulatory differences (8) may have been due to differences in fitness levels between subjects. A recent review paper

(12) supports this position by concluding that few differences in male and female responses to heat stress exist when groups are matched for $\dot{V}O_{2max}$.

Previous investigations have described the means by which heat acclimatization may be optimally achieved (3, 7, 11, 19, 20, 23). Investigations also have reported that strenuous exercise in a cool environment does not result in complete cross-adaptation with heat acclimatization (4, 19, 20, 23). However, the present investigation has demonstrated that these previously defined heat acclimatization principles do not apply to every climate and to every individual. During T_1, distance runners did not require 14.5 wk of heat exposure to maintain safe T_{re} in conditions which simulated the hottest days of summer (30.3°C) in the northeastern United States. These distance runners exhibited essentially the same physiological responses in the spring (T_1) as they did after 14.5 wk of summer running (T_2). Based upon these results, we conclude that highly trained distance runners who train in the northeastern United States (and similar climates) do not need special preparation for summer ultra-distance training. We recommend, however, that appropriate adjustments be made in heat acclimatization procedures if distance runners train or race at significantly higher exercise intensities (>60 to 65% $\dot{V}O_{2max}$) or in hotter climates (>30.3°C).

These findings may be utilized by exercise physiologists, coaches, athletic trainers, and physicians who prescribe heat acclimatization procedures or design running programs. Such individuals should recognize that summer training advice given to athletes must reflect local environmental conditions. In addition, hot weather running guidelines published by national or international organizations (1) should emphasize *regional* differences in the heat acclimatization needs of athletes. From these results, it appears that one set of heat acclimatization guidelines is not adequate for a continent which presents a spectrum of training environments.

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